

Accuracy of Cone Beam Computed Tomography, Photostimulable Phosphor Plate Digital Radiography and Conventional Radiography for Detection of Artificial Cancellous Bone Defects

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Abstract

Objectives: The optimal goal of radiography is to provide high-quality diagnostic images with the least patient radiation dose. The aim of this study was to evaluate the accuracy of cone-beam computed tomography (CBCT) and intraoral photostimulable phosphor plate (PSP) digital and film-based conventional radiography for detection of artificial cancellous bone defects.

Materials and Methods: Five dry human mandibles were used in this study. The mandibles were placed inside a water bath made of plexiglass plates; then PSP and CBCT scans were obtained. The mandibles were cut by a coping saw in buccolingual dimension and oval defects measuring 6.1×6.1 mm, 3×6.1 mm and 4×4 mm were created by a milling machine in the spongy bone. After fixing the two parts together (buccal and lingual), radiographs were repeated. Presence or absence of defects on images was evaluated and recorded by the two observers. Using SPSS 16, compatibility level, sensitivity, specificity and receiver operating curve (ROC) analysis were determined for each observer.

Results: The intraobserver agreement in all three imaging modalities was low to moderate ($\kappa \leq 0.613$). The inter-observer agreement in all the three imaging modalities was moderate ($\kappa = 0.406$). The area under the curve (AUC) of the imaging modalities in each observation was not significantly different. The area under the curve based on defect size for the two observers was not significantly different either.

Conclusion: Defects confined to spongy bone can be identified on film and PSP radiographs and CBCT scans. However, interpretation of PSP images and CBCT scans needs greater expertise and skills.

Key words: Cone-Beam Computed Tomography; Radiography, Dental, Digital; Bone and Bones; Dimensional Measurement Accuracy

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INTRODUCTION

The ability to detect changes in the cancellous bone structure, such as periapical and

periodontal lesions, would be a significant clinical asset in general dentistry as well as in endodontics and periodontics [1]. Accurate

diagnosis of subtle cancellous bone changes is desirable during the follow-up monitoring of peri-implant bone level [2]. Bone changes with respect to inflammatory diseases require a significant loss of bone mineral content to be radiologically evident [3]. Bender and Seltzer described the basic principles involved in detection of local resorptive bone lesions; the results indicated that because of the low mineral content of medullary bone, large resorptive lesions in this region could go undetected [4,5]. Furthermore, the cortices (particularly in the mandible) have a masking effect on lesions within the cancellous bone [6]. Different results have been obtained on the basis of anatomic and radiographic considerations with regard to detection of bone defects. Some studies on periapical lesions agreed with the theory of Bender and Seltzer [4,5,7-9]. Van der Stelt concluded that bone lesions are visible on radiographs only if the junction of the cortex and cancellous bone is eroded [10]. Digital radiography is an emerging area of diagnostic radiology with many potential benefits for dental practice [11]. Several studies have compared the accuracy of conventional and digital radiography and in most of them accuracy has been reported to be the same [12-16].

Yokota et al. showed that observers were somewhat better in detecting lesions confined to the lamina dura and cancellous bone when digital images were used as opposed to conventional radiographs [17]. Wallace et al. reported the accuracy of PSP images to be lower than that of films and reported the lack of image interpretation experience to be the reason [11]. Due to the physical nature of CBCT, it can hardly be compared with modern conventional CT in terms of low contrast resolution and noise level, but lesions affecting high-contrast structures could be detected with the same reliability as on CT scans [18]. Several studies have shown high ability of CBCT in detecting periapical lesions confined to cancellous bone and also lesions created on

cortical bone [9, 12,13, 18-22].

We could not find a study about the ability of CBCT in detecting lesions not necessarily related to teeth and confined to cancellous bone. Because of discrepancies in the results of previous studies, the aim of this study was to evaluate the accuracy of CBCT and intraoral PSP digital and film-based conventional radiography for detection of artificial cancellous bone defects.

MATERIALS AND METHODS

The defects were made on five dry human edentulous mandibles. The selected mandibles were intact without any cracks.

Preparation of the control group:

The mandibles were sectioned into three segments using a diamond disk with 30 mm diameter in a handpiece; one segment consisted of the canine-to-canine area and two others consisted of the posterior areas of the mandible. E-speed film (Eastman Kodak Company, Rochester, NY, USA) and PSP plates (Soredex-Union, Helsinki, Finland) were used for conventional and digital radiographic techniques, respectively. The unit of imaging was de Götzen (Xgenus, Rome, Italy). Imaging was carried out by a long cone and the distance between the source and film was 31 cm. Each mandibular section was mounted by glue parallel to the long axis of a plexiglass box to ensure reproducible relationship among the X-ray unit, object, and film/sensor. The walls of the plexiglass box were 3mm thick, and the distance between the walls was 30 mm. The box was filled with water during the exposures to simulate soft tissue. For imaging of the total body of the posterior segments, two films were used. The central X-ray was directed perpendicular to receptors at vertical and horizontal angles. Exposure rate was determined according to a pilot study and the voltage was set at 8mA and 70 kVp for both receptors, with exposure time of 0.2 to 0.25 seconds for films and 0.12 to 0.16 seconds for PSP sensors with regard to bone density.



Fig. 1. Imaging of posterior segment by E-speed film



Fig. 2. Sample of created defects on the buccal part after bone sectioning

Immediately after exposing each film, PSP sensor was exposed with the same geometry (Fig. 1). The body of the mandibles was marked with orthodontic wire to decrease the number of CBCT images; thus, CBCT images were divided into anterior and posterior regions similar to intra-oral images. The samples were fixed to the machine in a manner to direct the laser beam through the center of the long axis of the box. Imaging was carried out with voltage, current and time of 54 to 58 kVp, 6 mA and 12 seconds, respectively.

Preparation of defects:

Each osseous segment was sectioned into two buccal and lingual segments using a fine saw in a manner to leave more cancellous bone on the buccal segment. Defects were produced artificially within the osseous bone using a round bur; #V bur was used to produce round defects measuring 1.6 mm in diameter and oval defects measuring approximately 1.6×3 mm. Also, #XI bur was used to randomly create defects measuring approximately 4 mm in diameter in the anterior and posterior regions (Fig. 2). The lesion sizes were approximate due to high porosity of the dry bone, especially in the posterior region, and brittleness of the bony trabeculae. Of course, the approximate sizes of the defects had no negative effect on the diagnosis due to great differences in defect sizes. Subsequent to creation of the defects, the lingual plate was fixed adjacent to the buccal plate and images were captured similar to the method used for the control group.

After CBCT imaging, all the remaining cancellous bone of lingual plates was removed with an excavator and intraoral radiographs were repeated exactly the same as the former method.

Visualization of images:

The images were observed by two observers: one oral and maxillofacial radiologist and one oral and maxillofacial radiology post-graduate student in a dimly lit room. Intraoral films were set on the opaque frame made by pasteboard. The digital images were observed on a Samsung monitor (SyncMaster, MB 1793, Samsung, Gyeonggi-do, South Korea). The observers were allowed to change the density, contrast and magnification of the images. The CT images were submitted to the observers on a CD and visualized on a 17-inch monitor of a Dell laptop, with a resolution of 1440×900. There was no time limitation for viewing the images. Images were viewed again by each observer after two weeks.

Image interpretation:

The observers interpreted the absence or presence of defects with different sizes using a 5-point rating scale: Point 1: Definitely present, Point 2: Probably present, Point 3: Unsure, Point 4: Probably absent, Point 5: Definitely absent (Fig. 3).

In order to detect the defects on CBCT scans, first the image in the axial view was placed on the middle section and the sagittal axis of the image was placed in the direction of the sagittal axis of the software.

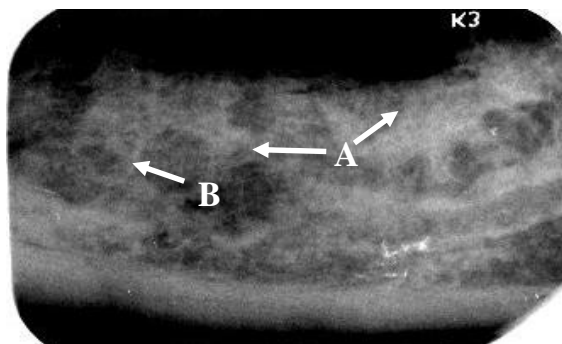


Fig. 3. PSP radiograph of created defects: (A) oval and (B) larger round defects

In the next step, the image in the sagittal view was evaluated by moving the mouse from the buccal bone towards the lingual bone; if the lesion was observed, the junction of the sagittal and coronal planes was placed at the center of the lesion and the lesion was evaluated on the coronal view in the next step. If the lesion was visualized on the coronal view, its presence was confirmed. The process was repeated for each quadrant. In the anterior views, adjustment of the sagittal and coronal planes of the bone on the axial view was separately carried out for each quadrant (Fig. 4).

Data analysis:

SPSS 16 was used for data analysis. Kappa coefficient was calculated to determine intra- and inter-observer agreement levels.

Agreement level was defined as follows: 0.0-0.200: poor, 0.201-0.400: fair, 0.401-0.600: moderate, 0.601-0.800: high, 0.801-1.0: excellent.

To determine the agreement level for the absence or presence of defects irrespective of the imaging modality, sensitivity and specificity of each technique, scores 1 and 2 of responses (definitely and probably present) were considered as the presence of defect and the three other responses were considered as the absence of defect, i.e. the 5-point rating scale changed into a 2-point rating scale. Z-test was used to compare sensitivity and specificity values. The accuracy of the methods was determined by ROC analysis and AUC.

RESULTS

To determine the agreement level, a 2-point rating scale was used and only absence or presence of defects was evaluated because the agreement level based on a 5-point rating scale was low.

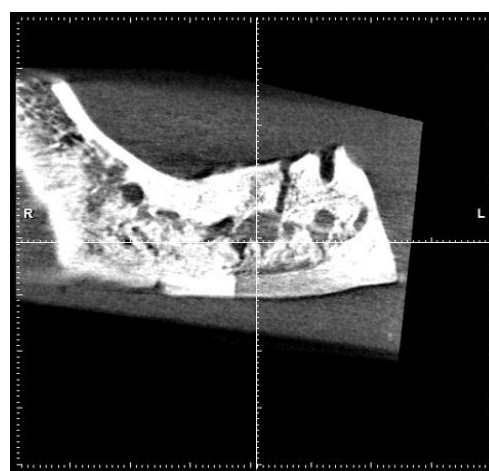


Fig. 4. White arrow shows a large round, black arrow shows a small round and diamond arrows show oval artificial lesions in the coronal and sagittal sections of CBCT scans.

Intra-observer agreement for both observers irrespective of the imaging modality was moderate ($\kappa \leq 0.544$). Inter-observer agreement for the first observation was also moderate ($\kappa = 0.406$). Intra- and inter-observer agreements with regard to imaging modality are presented in Table 1. According to Table 1, intra-observer agreements were moderate to high for E-speed film and CBCT scans ($0.525 \leq \kappa \leq 0.613$). Intra- and inter-observer agreements were the lowest for PSP digital radiography ($\kappa \leq 0.377$).

Sensitivity of CBCT and PSP digital radiography was significantly higher than that of E-speed film-based radiography ($P < 0.01$). However, there were no significant differences between CBCT and PSP digital radiography ($P = 0.12$). There were no significant differences in the specificity of E-speed film, PSP and CBCT. Sensitivity and specificity of both observers with regard to imaging modality are presented in Table 2. Sensitivity and specificity of imaging modalities were higher for the first observer and this difference was statistically significant for PSP ($P < 0.001$) and CBCT ($P < 0.01$).

The first observer's data are presented in Table 3 (the second observer's data are not shown here).

Table 3 shows that removal of the cancellous bone remaining between the created defects and cortical bone (junctional bone) increased the specificity of PSP digital and film-based conventional radiographs. The highest sensitivity was related to CBCT scans in all defect sizes.

The accuracy $[(\text{true positive} + \text{true negative}) \div \text{total observations}]$ of both observers was measured and compared with the AUC and the related confidence intervals. The AUC was significantly higher for the first observer, $[0.815 \text{ (CI: } 0.783\text{-}0.847) \text{ vs. } 0.687 \text{ (CI: } 0.648\text{-}0.726)]$, Graph 1). According to Table 4, this difference was not significant for E-speed films, $[0.794 \text{ (CI: } 0.736\text{-}0.853) \text{ vs. } 0.746 \text{ (CI: } 0.685\text{-}0.811)]$.

Table 4 shows that accuracy of CBCT for the first observer (AUC=0.838) and E-speed film for the second observer (AUC=0.748) was the highest but at a confidence level of 95% there were no significant differences among the results of E-speed film, PSP and CBCT.

Table 1. Kappa coefficients with regard to imaging modalities

	Imaging modality		
	E-speed film	PSP	CBCT
Intra-observer agreement			
First observer	0.609	0.377	0.610
Second observer	0.525	0.235	0.613
Inter-observer agreement			
First observation	0.488	0.201	0.308

Table 2. Sensitivity and specificity of first and second observers with regard to imaging modality

	E-speed film		PSP		CBCT	
	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
First observer	81.7	67	90	55	91	75
Second observer	77.5	64	55.7	25	80	57

According to Table 5, there were no statistically significant differences in the accuracy of imaging modalities among different sizes of defects or among different sizes of defects in each imaging modality.

DISCUSSION

Diagnosis of cancellous bone defects is important in both the process of periodontal and periapical diseases and also diseases not necessarily affecting teeth, such as inflammatory or tumoral lesions, which are prevalent in older age groups.

Therefore, edentulous mandibles were chosen to evaluate cancellous bone defects in this study. The size of the lesions was larger than 1.5 mm due to the limitation of radiography in identifying undersized lesions according to previous studies [23,24] and also due to the fact that pathological changes have not been reported to be small in clinical studies [25].

The method described by Stavropoulos and Wenzel [12] was used for bone sectioning. Barbat and Messer [14] reported high success of this method for creating artificial periapical lesions confined to cancellous bone.

Table 3. Sensitivity and specificity of first observer with regard to created defects' size, group and imaging modality

	Imaging modality					
	E-speed film		PSP		CBCT	
	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
Size I*						
Group I †	65	68	65	85	70	85
Group II ††	60	90	65	95		
Size II**						
Group I	60	75	60	95	75	80
Group II	60	99	55	100		
Size III***						
Group I	75	65	75	90	80	95
Group II	75	95	75	100		

†: Before removal of junctional bone

††: After removal of junctional bone

* Artificial defects measuring 1.6×1.6 mm²

** Artificial defects measuring 1.6×3 mm²

*** Artificial defects measuring 4×4 mm²

Table 4. Area under the ROC curve for the two observers with regard to imaging modality

	Imaging method		
	PSP	CBCT	E-speed film
	AUC (CI)	AUC (CI)	AUC (CI)
First observer	0.794 (0.736,0.853)	0.797 (0.740,0.854)	0.838 (0.784,0.892)
Second observer	0.746 (0.685,0.811)	0.650 (0.581,0.720)	0.673 (0.604,0.742)

The method described by Kullendroff and Nilsson [15] and Kullendroff et al. [16] was used to simulate soft tissue. Due to limitations in previous methods for CBCT imaging, we placed the mandibles in a water bath instead of placing a water bath between the mandible and the X-ray source.

Pinsky et al, [26], Gaia et al, [27] and Marques et al, [28] also used water baths for 3D imaging in their studies. Accuracy of the CBCT and PSP was significantly different between the two observers. It can be concluded that interpretation of the CBCT scans requires more experience than the two other types of radiographs. Noujeim et al, who evaluated periodontal lesions in cancellous bone also believe that in order to better interpret CBCT scans, observers should be trained [19]. Pinsky et al. created lesions in cortical bone and reported that interpreting CBCT images was not observer-dependent [26].

Discrepancy in the results might be attributed to the type of lesions. They also believed that the same results might not be obtained in cancellous bone of patients. There were no significant differences in the accuracy of E-speed film, PSP and CBCT for each observer (Table 4). Noujeim et al, in their study on periodontal lesions showed that CBCT displayed periodontal lesions significantly better than film, which was inconsistent with the results of the current study [19].

In a comparative study by Kullendroff et al, on the accuracy of E-speed films and PSP digital radiographs for detection of periapical lesions, there were no significant differences between these methods [16].

There were no significant differences between the accuracy of conventional X-ray images and radiovisiography in the diagnosis of lesions larger than 1.25 mm in a study by Stassinakis et al, consistent with the results of our study shown in Table 5 [29].

Among the imaging modalities, the intra-observer agreement was the highest for CBCT ($\kappa \geq 0.610$) and inter-observer agreement for the first observation was the highest for E-speed film ($\kappa = 0.480$) (Table 1). Gaia et al. created lesions with similar sizes in cortical bone, and obtained high agreement levels for CBCT images ($\kappa = 0.869$) [27].

Kaeppler et al. created peri-implant intraosseous defects and obtained high inter- and intra-observer agreements ($\kappa \leq 0.850$) with lesions smaller than those created in our study (0.7-1.4 mm in diameter) with E-speed films and PSP [30]. The CBCT densities vary in different bone densities, which is particularly true with the use of edentulous dry mandibles since trabeculations are extensive and only contrast with air, making the interpretation of the images more difficult; therefore, the agreement level and accuracy in our study were relatively low.

Table 5. Area under the ROC curve for the first observer with regard to imaging modality and artificial defects' size

	Size I	Size II	Size III
	AUC (CI)	AUC (CI)	AUC (CI)
E-speed film	0.774 (0.879,0.668)	0.783 (0.885,0.740)	0.832 (0.925,0.738)
PSP	0.836 (0.928,0.745)	0.777 (0.884,0.581)	0.775 (0.876,0.674)
CBCT	0.824 (0.921,0.728)	0.832 (0.928,0.736)	0.860 (0.949,0.771)

The lowest intra- and inter-observer agreement was observed with PSP ($\kappa \leq 0.377$). Comparison of the sensitivity and specificity of the modalities showed that their sensitivity was higher than their specificity (Table 2), probably because the observers were not blind to the presence of defects (since they were directly asked to detect intraosseous defects) and thus, bone marrows were misinterpreted as defects, and this was inevitable.

For both observers, PSP and CBCT scans had the highest sensitivity; CBCT had the highest specificity, and the lowest specificity belonged to PSP (Table 3). These results and low agreement level for PSP radiographs indicate that: 1. Interpretation of PSP images requires more expertise similar to CBCT scans. 2. Changes in density and contrast might increase positive cases, especially false ones. In a study by Katsarsky et al, sensitivity of PSP was lower than that of films because brightness and contrast of PSP images were not allowed to change [6].

Evaluation of the effect of defect size on sensitivity, specificity and agreement level indicated that increasing the size of defects resulted in an increase in sensitivity in round defects. The effect of defect location on their detection was not evaluated because of limited number of samples. Larger defects in the anterior regions might be detected easier because of smaller bone marrow spaces. Shoha et al. detected experimental peri-apical lesions on radiographs at premolar areas but not at molar areas [31].

Removal of cancellous bone between the lesion and cortical bone (junctional bone) increased the specificity of E-speed films and PSP comparable to that of CBCT; this increase was greater for E-speed films, especially for large round defects (Table 3). However, this increase was not statistically significant in any of the sizes. In some studies, only a few defects were visible [1,11,13] while in some other studies most defects were visible without erosion of junctional bone [14-16,32,33].

Some of the inconsistencies in the results of studies may be due to varying amounts of junctional bone in the experimental defects.

Considering the overall diagnostic accuracy, sensitivity and specificity of imaging modalities, it can be concluded that lesions confined to cancellous bone are identifiable on films, PSP radiographs and CBCT scans. Barbat and Messer discussed that not detecting the lesions confined to cancellous bone may be due to the methodology involving creation of lesions through apical openings in extraction sockets by use of various files and burs. By sectioning the mandible buccolingually, the surrounding trabecular bone can be removed to form a "hollow"-type lesion, thereby mimicking the characteristics of a naturally occurring lesion [14]. Similar findings were obtained in an in vivo study by Marmary et al on periapical lesions confined to cancellous bone [34]. However, they did not discuss whether these findings had anything to do with the loss of bone trabeculae close to the cortical bone or not. An ex vivo study by Jorge et al, on dog's teeth yielded contradictory results. In their study, small lesions were not identifiable on indirect digital images [25]. Probably acute phase of the created lesions led to failed detection of lesions because at least 20–40% of mineral content of bone should be lost so that the lesion can be detected on intraoral radiographs.

The results of the current and similar studies in which defects were created by bur in dry bone may differ from the in vivo situation because of well-defined defects and many other confounding factors.

CONCLUSION

Defects confined to spongy bone can be identified on film and PSP radiographs and CBCT scans. However, interpretation of PSP images and CBCT scans needs greater expertise and skills.

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